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(54) **WAVEGUIDE CONNECTING STRUCTURE,
ANTENNA DEVICE AND RADAR DEVICE**

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See application file for complete search history.

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(56) **References Cited**

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U.S. PATENT DOCUMENTS

4,720,691 A 1/1988 Rammos
5,579,019 A 11/1996 Uematsu et al.

(Continued)

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FOREIGN PATENT DOCUMENTS

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JP 7-106847 A 4/1995
JP 2001-156510 A 6/2001

(Continued)

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OTHER PUBLICATIONS

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(57) **ABSTRACT**

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H01P 3/00 (2006.01)
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H01P 5/19 (2006.01)
H01P 5/12 (2006.01)
G01S 13/44 (2006.01)

There is provided a waveguide connecting structure, includ-
ing first, second, third and fourth waveguides. A first coupling
window at one of magnetic field planes of the third waveguide
couples the first and third waveguides in such a manner that
the electric field planes of both are in parallel. A second
coupling window formed at one of the electric field planes of
the third waveguide couples the second and third waveguides
in such a manner that the electric field planes of the second
waveguide is in parallel with the magnetic field planes of the
first waveguide. A third coupling window formed at the other
one of the electric field planes couples the fourth and third
waveguides in such a manner that the electric field planes of
the fourth waveguide is in parallel with the magnetic field
planes of the first waveguide.

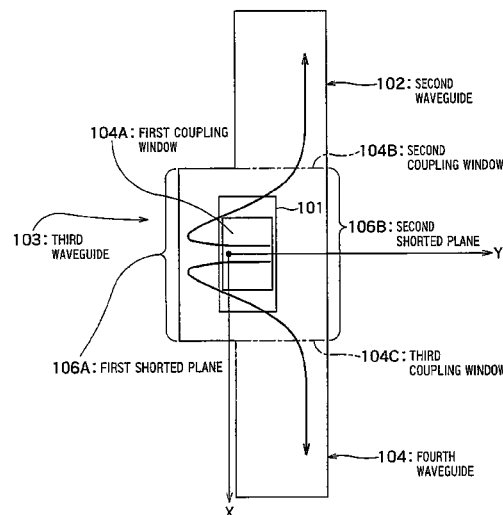
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US 9,331,371 B2

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(56)

References Cited

2013/0314172 A1 * 11/2013 Massman H01P 5/20
333/122

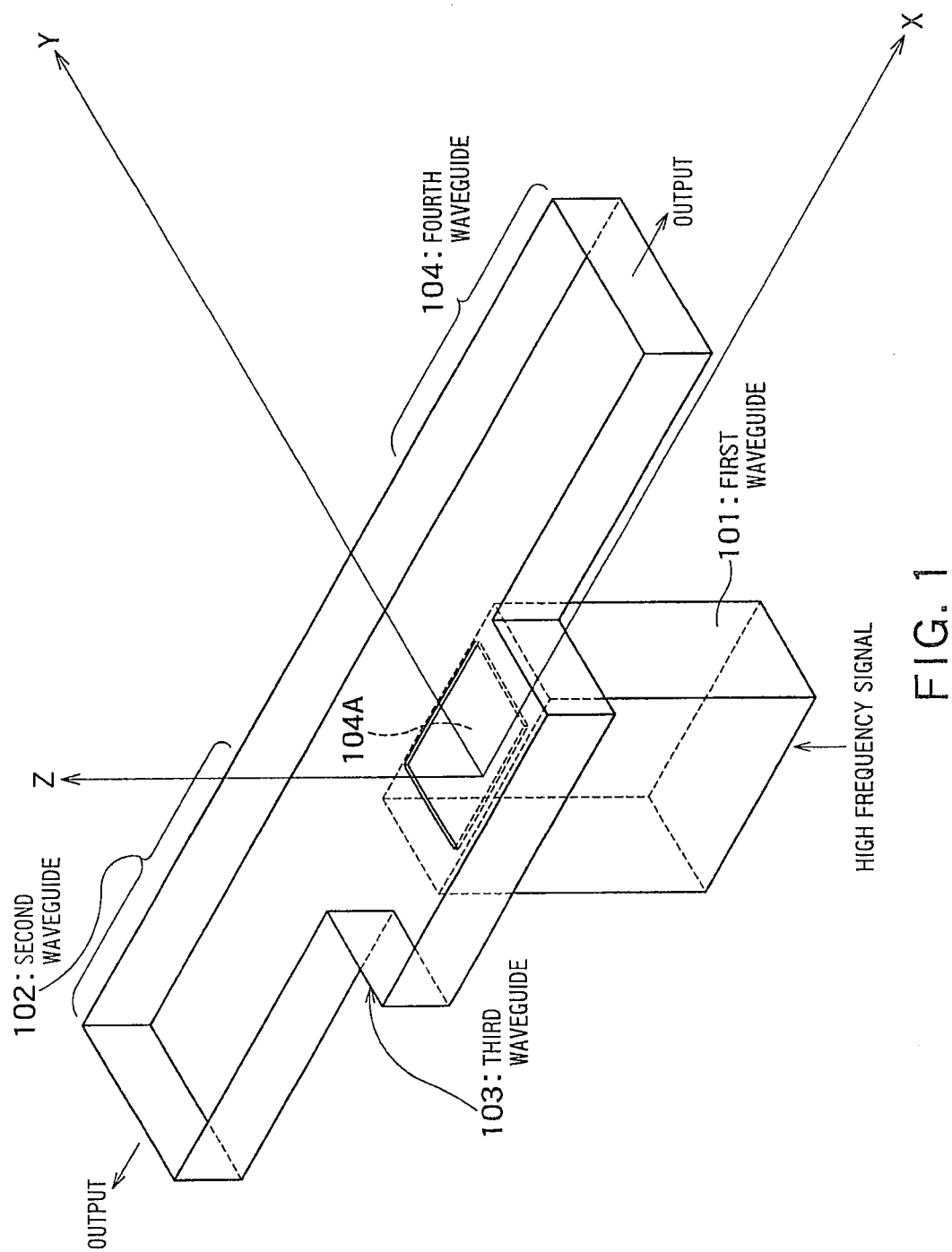
U.S. PATENT DOCUMENTS

6,563,398 B1 * 5/2003 Wu H01Q 21/0037
333/137
7,750,762 B2 7/2010 Okano
8,169,363 B2 5/2012 Shijo et al.
8,305,260 B2 11/2012 Shijo et al.
2008/0238579 A1 * 10/2008 Okano H01P 1/02
333/21 A
2010/0123619 A1 5/2010 Shijo et al.
2013/0154764 A1 * 6/2013 Runyon H01P 5/12
333/135

FOREIGN PATENT DOCUMENTS

JP 2011-149898 A 8/2011
JP 4825250 9/2011
JP 4996640 5/2012
JP 2012-199659 10/2012
WO WO 2005/099026 A1 10/2005

* cited by examiner



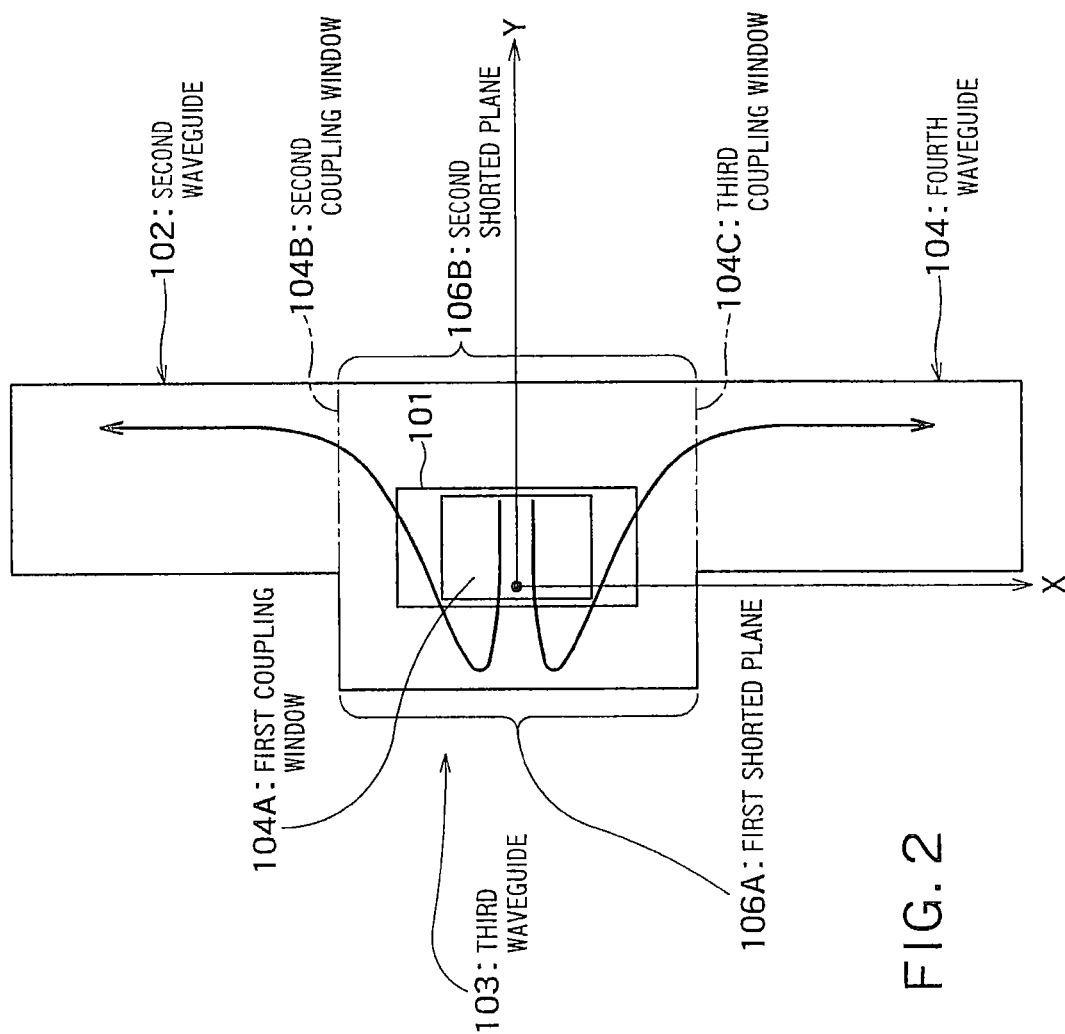


FIG. 2

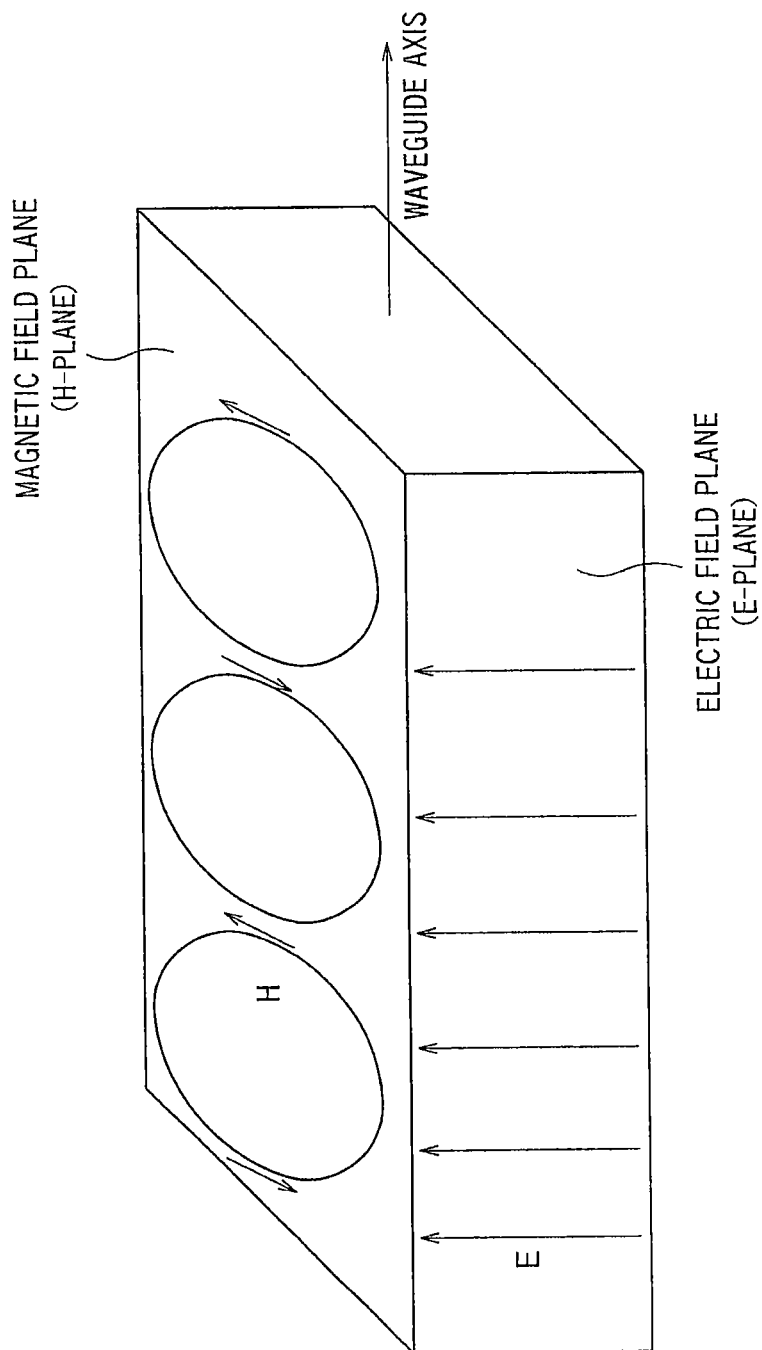
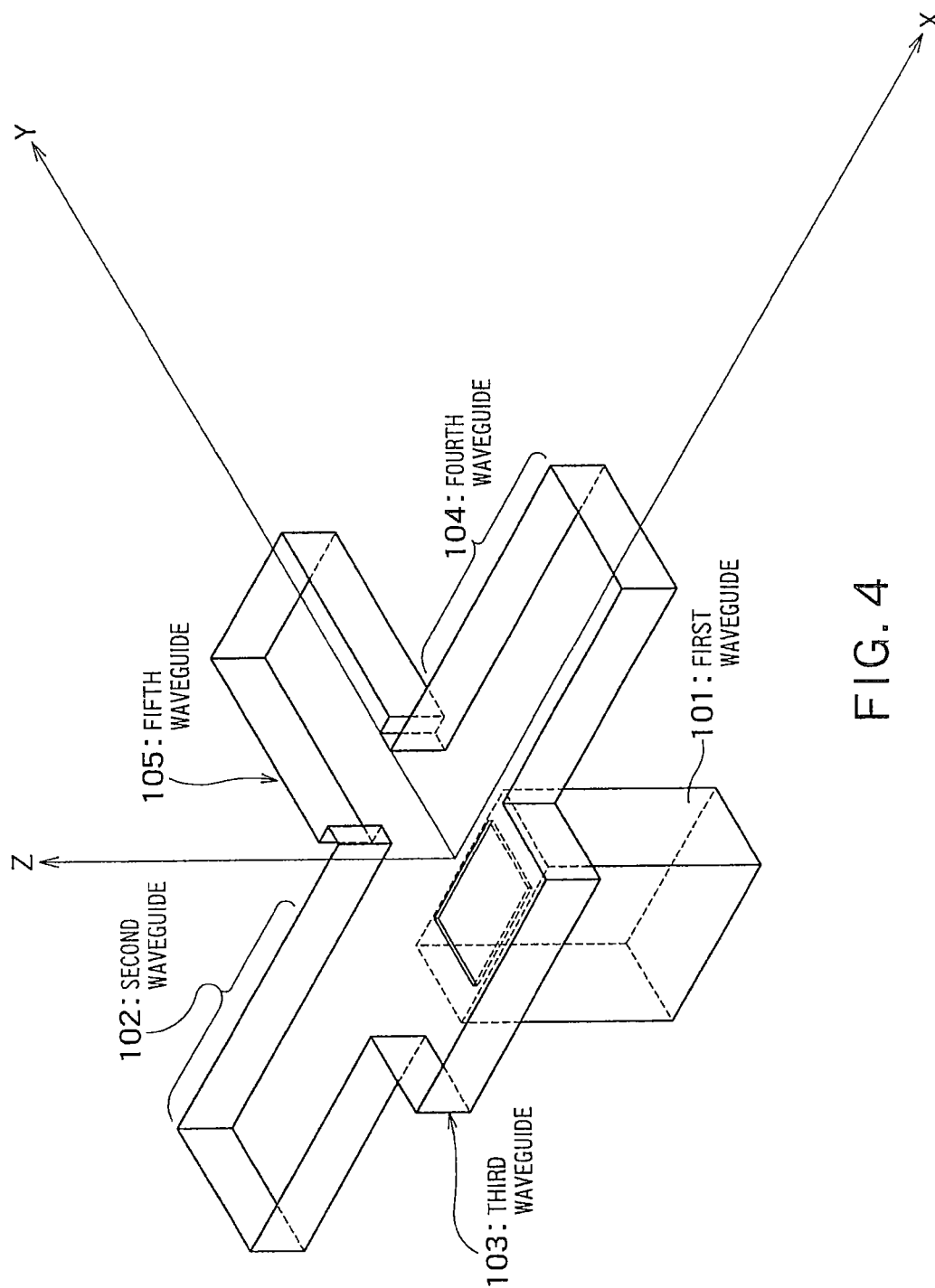
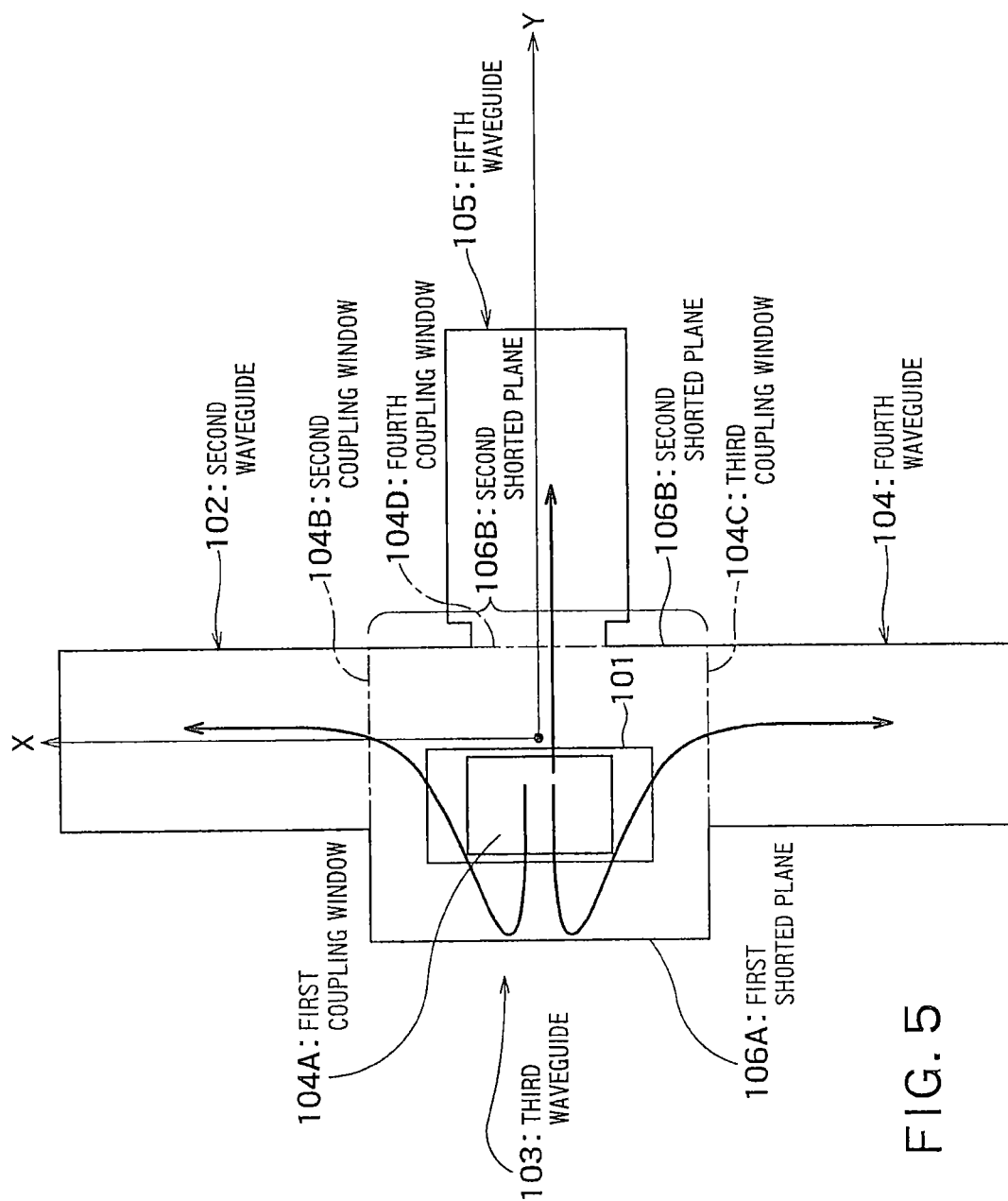
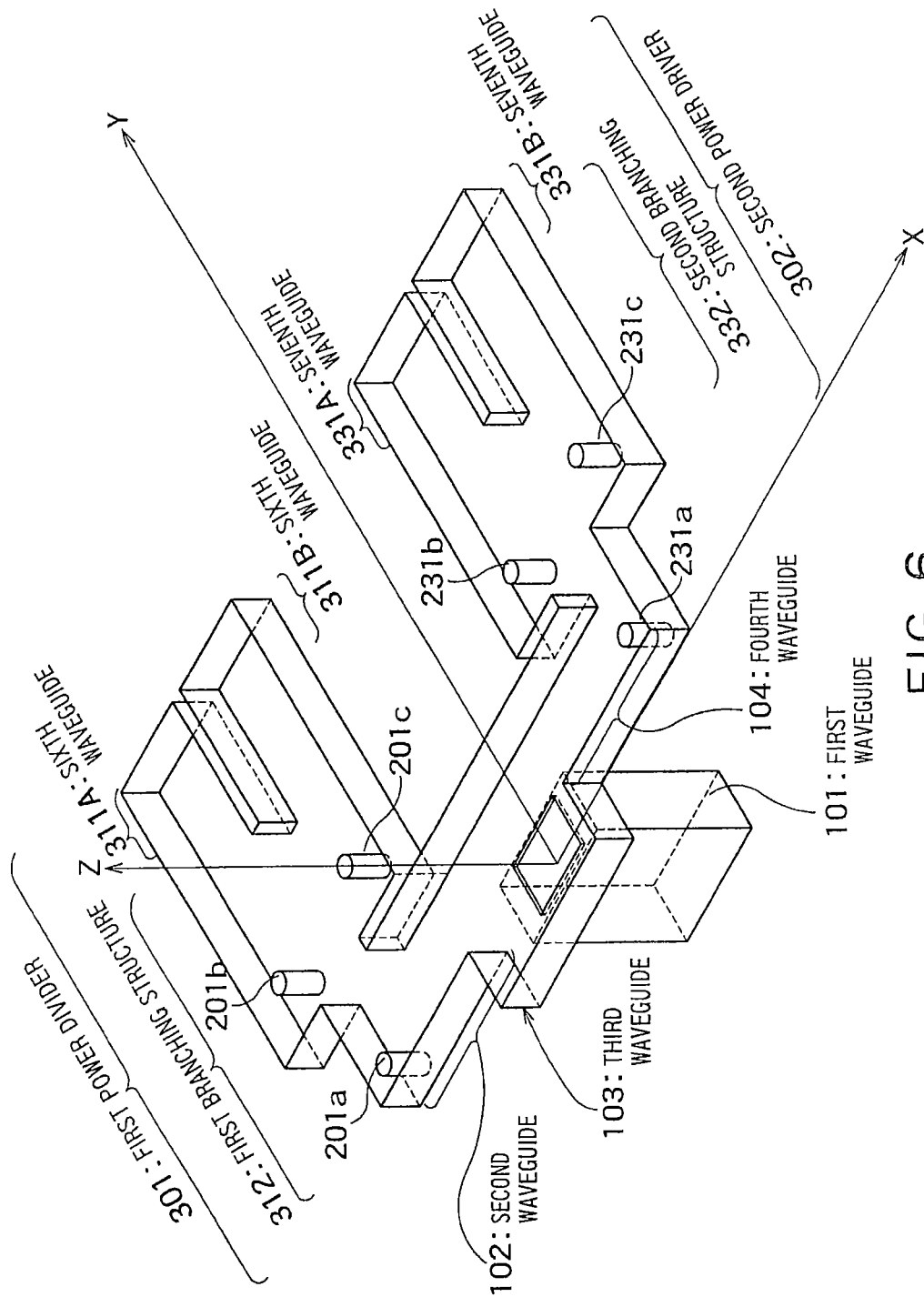
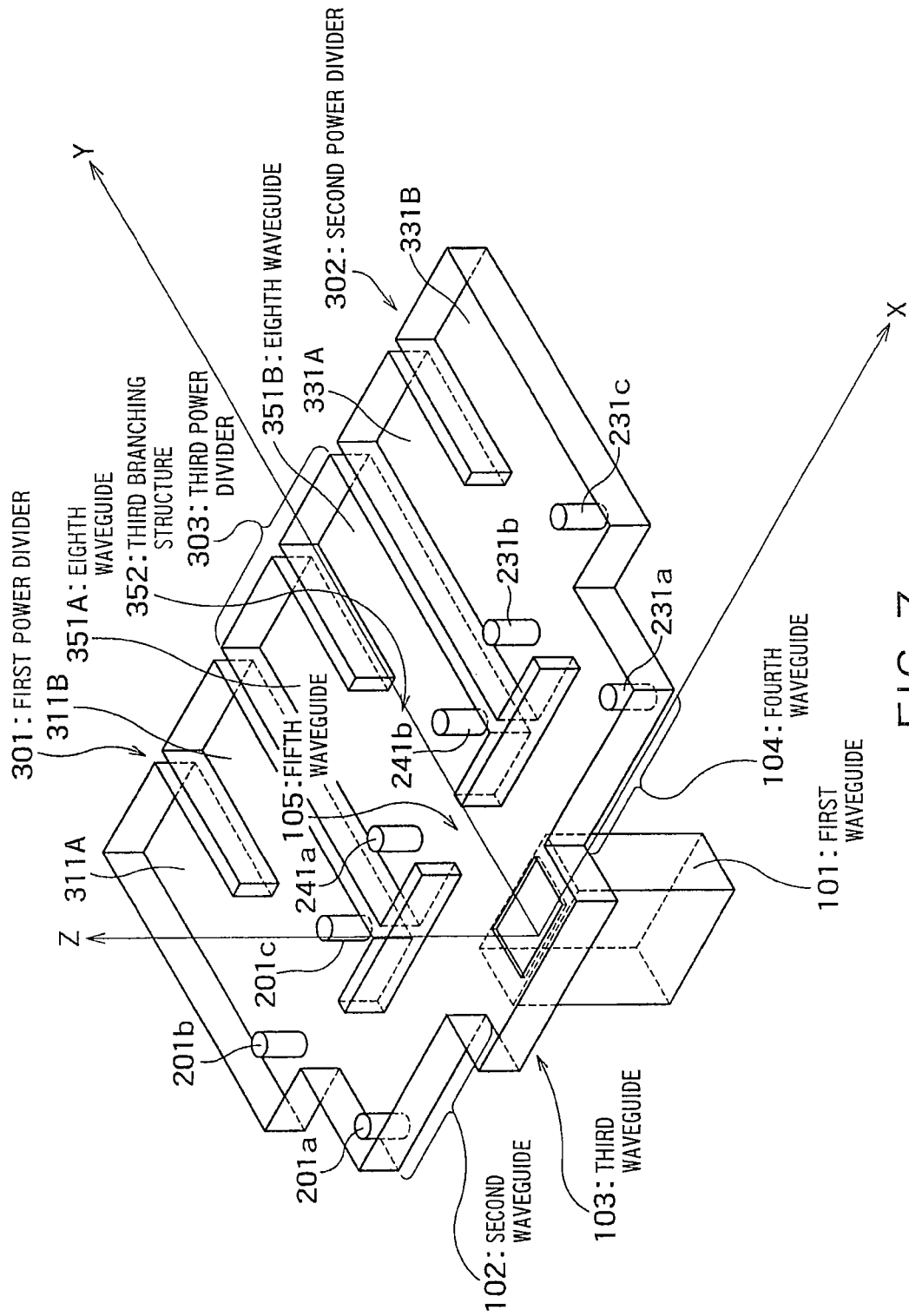


FIG. 3









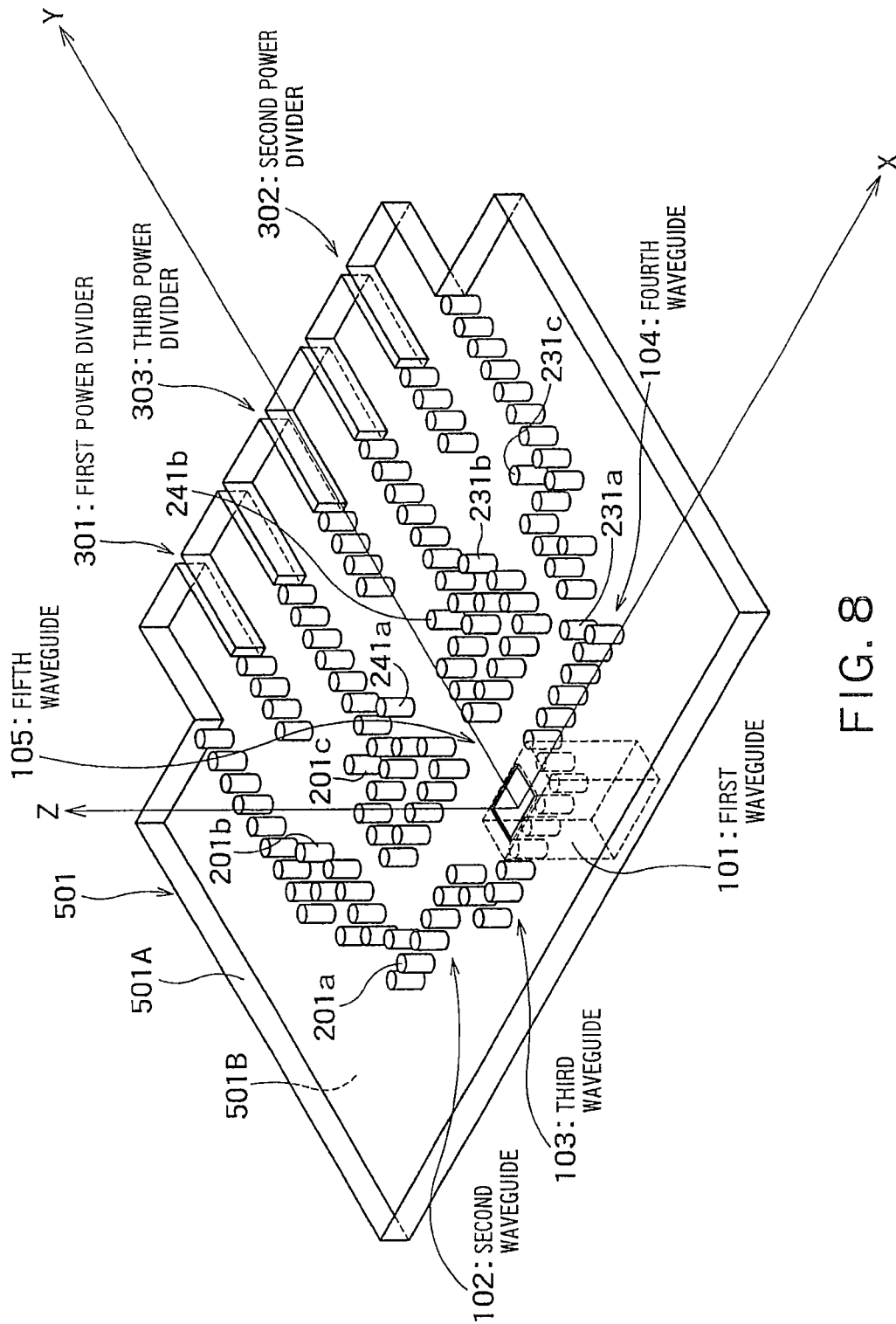


FIG. 8

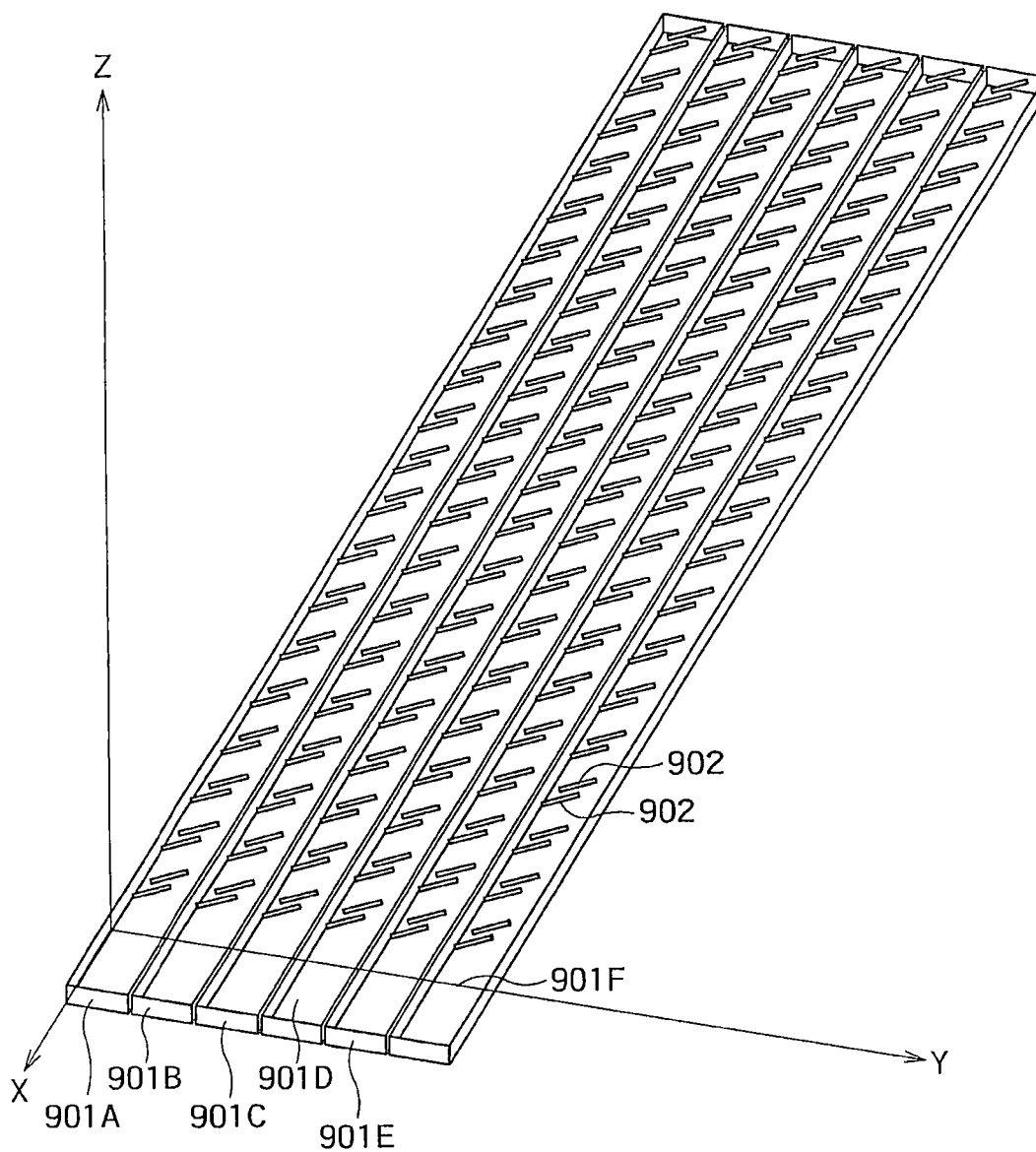


FIG. 9

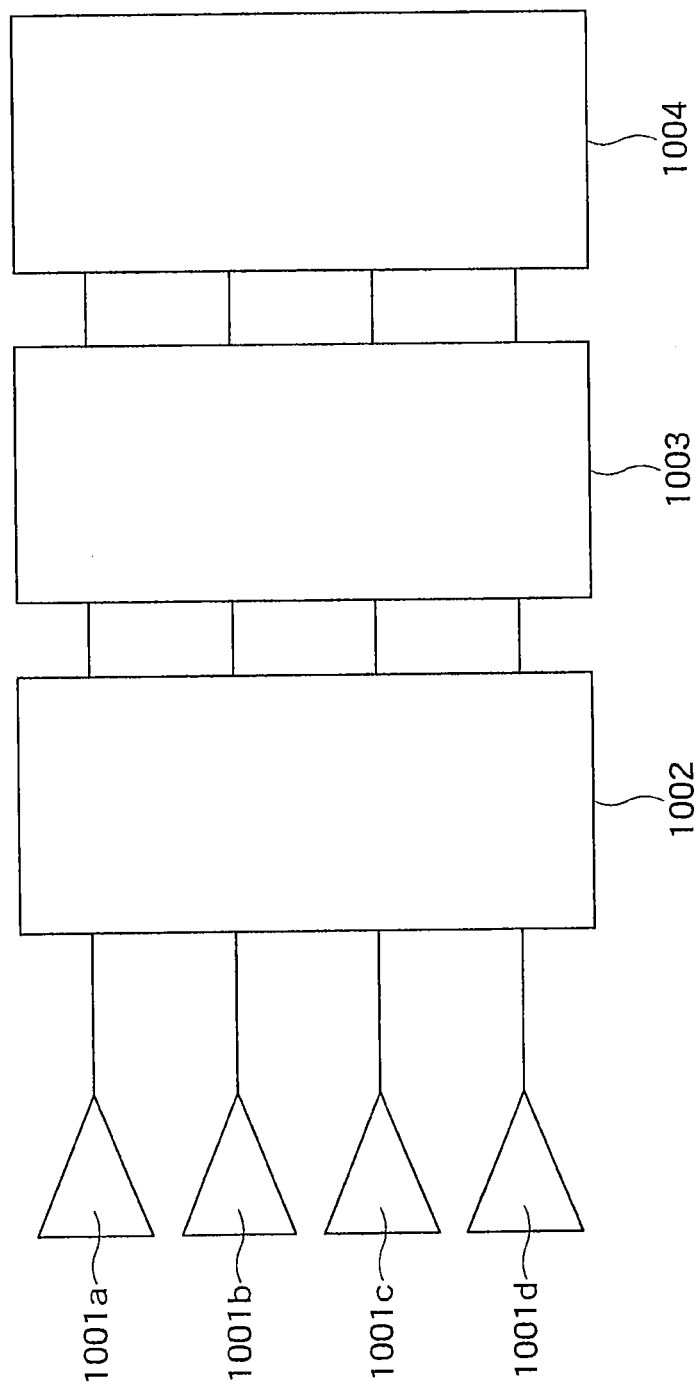


FIG. 10

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WAVEGUIDE CONNECTING STRUCTURE, ANTENNA DEVICE AND RADAR DEVICE

CROSS REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from the prior Japanese Patent Application No. 2012-157720 filed on Jul. 13, 2013, the entire contents of which are incorporated herein by reference.

FIELD

Embodiments described here relate to a waveguide connecting structure, an antenna device and a radar device.

BACKGROUND

There is known a waveguide bend that connects two waveguides which differ in waveguide axis direction. The conventional waveguide bend connects waveguides so that respective electric field planes (E-planes) or magnetic field planes (H-planes) of the two waveguides that are connected is in parallel with each other.

There is known a post wall waveguide (also called a dielectric waveguide or a substrate integrated waveguide and the like) that is constituted of a via-hole array that is formed on a dielectric substrate, and copper foils bonded onto both surfaces of the dielectric substrate. As a coupler that connects a post wall waveguide and a waveguide, there is a coupler that uses a bend structure.

In the conventional waveguide bend structure described above, the E-planes or the H-planes of the two waveguides that differ in waveguide axis direction are disposed to be parallel with each other. However, the disposition is sometimes required so that the H-planes of one of the waveguides and the E-planes of the other one of the waveguides is in parallel. If both are coupled so that the H-planes of one of the waveguides and the E-planes of the other one of the waveguides are parallel with each other, signals cannot be coupled between these waveguides. For example, when a high-frequency signal of a TE₁₀ mode is inputted from one of the waveguides, the high-frequency signal is brought into a TM mode having an electric field component in the waveguide axis direction, with respect to the other one of the waveguides. Therefore, the high-frequency signal has a higher-order mode with respect to the other one of the waveguides to be cut off and cannot be coupled.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a waveguide connecting structure according to a first embodiment;

FIG. 2 is a top view of the structure shown in FIG. 1;

FIG. 3 is an explanatory view of a magnetic field plane and an electric field plane;

FIG. 4 is a perspective view of a waveguide connecting structure according to a second embodiment;

FIG. 5 is a top view of the structure of FIG. 4;

FIG. 6 is a perspective view of a waveguide connecting structure according to a third embodiment;

FIG. 7 is a perspective view of a waveguide connecting structure according to a fourth embodiment;

FIG. 8 is a perspective view of a waveguide connecting structure according to a fifth embodiment;

FIG. 9 is a view showing an example of a slot array antenna according to a sixth embodiment; and

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FIG. 10 is a view showing an example of a radar device according to a seventh embodiment.

DETAILED DESCRIPTION

According to some embodiments, there is provided a waveguide connecting structure, including a first waveguide, a second waveguide, a third waveguide and a fourth waveguide.

The first waveguide includes a pair of electric field planes and a pair of magnetic field planes.

The second waveguide includes a pair of electric field planes and a pair of magnetic field planes.

The third waveguide includes a pair of electric field planes and a pair of magnetic field planes.

The fourth waveguide includes a pair of electric field planes and a pair of magnetic field planes.

The third waveguide has a first coupling window formed at one of the magnetic field planes of the third waveguide, a second coupling window formed at one of the electric field planes of the third waveguide, a third coupling window formed at the other one of the electric field planes of the third waveguide, and a first shorted plane and a second shorted plane that close ends of the third waveguide.

The first coupling window couples one end of the first waveguide to the third waveguide in such a manner that the electric field planes of the first waveguide are in parallel with the electric field planes of the third waveguide.

The second coupling window couples one end of the second waveguide to the third waveguide in such a manner that the electric field planes of the second waveguide is in parallel with the magnetic field planes of the first waveguide.

The third coupling window couples one end of the fourth waveguide to the third waveguide in such a manner that the electric field planes of the fourth waveguide is in parallel with the magnetic field planes of the first waveguide.

Hereinafter, embodiments will be described with reference to the drawings.

First Embodiment

FIG. 1 is a perspective view of a waveguide connecting structure according to a first embodiment. FIG. 2 is a top view (view seen from above in a Z-axis direction) of the structure.

The waveguide connecting structure of FIG. 1 includes a first waveguide **101**, a second waveguide **102**, a third waveguide **103** and a fourth waveguide **104**. Waveguide axis directions of the second waveguide **102** and the fourth waveguide **104** are the same. The waveguide axis directions (X-axis direction) of the second waveguide **102** and the fourth waveguide **104**, a waveguide axis direction (Y-axis direction) of the third waveguide **103**, and a waveguide axis direction (Z-axis direction) of the first waveguide **101** are orthogonal to each other.

The waveguides **101** to **104** are each formed by a pair of electric field planes (E-planes) and a pair of magnetic field planes (H-planes). As shown in FIG. 3, a plane with a wide width along the waveguide axis direction corresponds to the H-plane, and a narrow plane corresponds to the E-plane. The electric field planes and the magnetic field planes of the waveguides **101** to **104** are formed by metallic plates such as a copper, for example.

The magnetic field planes (H-planes) of the first waveguide **101**, and the electric field planes (E-planes) of the second waveguide **102** and the fourth waveguide **104** are parallel with

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each other. Further, the E-planes of the first waveguide 101 and the E-planes of the third waveguide 103 are parallel with each other.

Both ends of the first waveguide 101, the second waveguide 102 and the fourth waveguide 104 are opened.

Both ends of the third waveguide 103 are closed by shorted planes 106A and 106B, as shown in FIG. 2. Note that the shorted plane 106B continues to one of the respective E-planes of the second waveguide 102 and the fourth waveguide 104 to form the same plane.

Further, the third waveguide 103 is provided with coupling windows 104A, 104B and 104C.

The coupling window 104B is provided at one of the E-planes of the third waveguide 103. One end of the second waveguide 102 is coupled to the third waveguide 103 via the coupling window 104B. At this time, the E-planes of the second waveguide 102 are parallel with the H-planes of the first waveguide 101. Namely, the coupling window 104B couples the E-planes of the second waveguide 102 and the H-planes of the first waveguide 101 parallel with each other. The other end of the second waveguide 102 is an input/output port for a high-frequency signal.

Likewise, the coupling window 104C is provided at the other one of the E-planes of the third waveguide 103. One end of the fourth waveguide 104 is coupled to the third waveguide 103 via the coupling window 104C. At this time, the E-planes of the fourth waveguide 104 are parallel with the H-planes of the first waveguide 101. Namely, the coupling window 104C couples the E-planes of the fourth waveguide 104 and the H-planes of the first waveguide 101 parallel with each other. The other end of the second waveguide 104 is an input/output port for a high-frequency signal.

In the present example, the second waveguide 102 and the fourth waveguide 104, and the third waveguide 103 are integrally formed physically. Part or all of them may be formed by folding from one metallic plate, or may be formed by bonding a plurality of metallic plate members. In the present example, the H-planes of the second waveguide 102 and the fourth waveguide 104, and the H-planes of the third waveguide 103 continue to form the same plane at the same height. The H-planes of the second waveguide 102 and the fourth waveguide 104, and the H-planes of the third waveguide 103 may be at different heights respectively. The third waveguide 103 forms H-bend structures respectively with the second waveguide 102 and the fourth waveguide 104.

The coupling window 104A is formed at the H-plane (lower side) of the third waveguide 103. In the coupling window 104A, a size of a side that is parallel with the shorted plane 106A is longer than a side that is perpendicular to the shorted plane 106A.

One end of the first waveguide 101 is coupled to the third waveguide 103 via the coupling window 104A. At this time, the E-planes of the first waveguide 101 and the E-planes of the third waveguide 103 are parallel with each other. Namely, the coupling window 104A couples the E-planes of the first waveguide 101 and the E-planes of the third waveguide 103 parallel with each other. At one end of the first waveguide 101, an opening thereof is narrowed to be adapted to a shape of the coupling window 104A. The other end of the first waveguide 101 is an input/output port for a high-frequency signal.

Note that if the size of the coupling window 104A is adapted to a line width of the first waveguide 101, the opening of the first waveguide 101 does not have to be narrowed. In the present example, the first waveguide 101 and the third waveguide 103 are separately configured, and are coupled by positioning, but the first waveguide 101 and the third waveguide 103 may be integrally formed physically.

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The waveguide connecting structure of FIG. 1 enables transmission of a high-frequency signal from the first waveguide 101 to the second waveguide 102 and the fourth waveguide 104, by interposing the third waveguide 103 between the first waveguide 101, and the second waveguide 102 and the fourth waveguide 104. An operation thereof will be described as follows.

When a high-frequency signal of a TE₁₀ mode is inputted from the first waveguide 101, the high-frequency signal has a high-order mode having an antisymmetric electromagnetic field shape such as a TE₂₀ mode and a TE₄₀ mode. Therefore, if the third waveguide is not provided, and one end of the first waveguide 101 is coupled to the H-plane of the second or the fourth waveguide, the high-frequency signal is not coupled to the second or the fourth waveguide, and is cut off. In contrast with this, when the third waveguide 103 is interposed as in the present embodiment, the E-planes of the first and the third waveguides are parallel with each other, and therefore, the high-frequency signal from the first waveguide is coupled to the third waveguide first. The high-frequency signal which is coupled to the third waveguide reflects on the shorted plane 106A of the third waveguide 103 as shown in FIG. 2. The H-planes of the third waveguide 103, and the H-planes of the second waveguide 102 and the fourth waveguide 104 are parallel with each other, and therefore, the high-frequency signal which is reflected on the shorted plane 106A is coupled to the second waveguide 102 and the fourth waveguide 104 respectively, and is transmitted to the respective openings. By the above operation, the high-frequency signal which flows in the first waveguide 101 is also propagated to the second waveguide 102 and the fourth waveguide 104 which are disposed in such a manner that the E-planes thereof are not parallel with the E-planes of the first waveguide. The present waveguide connecting structure is operated as a two-branch power divider.

Conversely, also when electromagnetic waves (high-frequency signals) of a TE₁₀ mode are inputted from the second waveguide and the fourth waveguide, the electromagnetic waves are respectively coupled (power synthesis) to the first waveguide via the third waveguide by the inverse operation from the above description. If the third waveguide is not provided, the high-frequency signals that are inputted from the second waveguide and the fourth waveguide each have a TM mode having an electric field component in the waveguide axis direction, with respect to the first waveguide, are cut off as a high-order mode, and are not coupled to the first waveguide.

As above, according to the present embodiment, the third waveguide 103 having the E-planes parallel with the E-planes of the first waveguide 101, and having the H-planes parallel with the H-planes of the second waveguide 102 and the fourth waveguide 104 is interposed between the first waveguide 101, and the second waveguide 102 and the fourth waveguide 104, whereby transmission of a high-frequency signal from the first waveguide 101 to the second waveguide 102 and the fourth waveguide 104 is enabled.

Second Embodiment

FIG. 4 is a perspective view of a waveguide connecting structure according to a second embodiment. FIG. 5 is a top view of the structure. The elements with the same names in FIGS. 1 and 2 are assigned with the same reference signs, and the redundant description will be omitted except for changed parts.

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A main point that is different from the first embodiment lies in that a fifth waveguide **105** is added. The shorted plane **106B** of the third waveguide **103** is provided with a fourth coupling window **104D**.

The fifth waveguide **105** is formed by a pair of electric field planes (E-planes) and a pair of magnetic field planes (H-planes). Both ends of the fifth waveguide **105** are opened. One end of the fifth waveguide **105** is coupled to the third waveguide **103** via the fourth coupling window **104D**. H-planes of the fifth waveguide **105** are parallel with the H-planes of the third waveguide **103**. Further, E-planes of the fifth waveguide **105** are parallel with the E-planes of the first waveguide. The other end of the fifth waveguide **105** is an input/output port for a high-frequency signal.

A high-frequency signal of a basic mode, a TE₁₀ mode that is inputted from the first waveguide **101** is coupled to the second and the fourth waveguides via the third waveguide by the same principle as the first embodiment, and further in the present embodiment, the high-frequency signal is also coupled to the fifth waveguide. Namely, as shown in FIG. 5, the signal which is reflected on the shorted plane **106A** of the third waveguide is coupled to the second, the fourth and the fifth waveguides the H-planes of which are parallel with those of the third waveguide, respectively. Namely, the signal is branched into three, and is transmitted to the openings of the second, the fourth and the fifth waveguides. Accordingly, the present structure operates as a three-branch power divider.

As above, according to the present embodiment, the third waveguide **103** that has the E-planes parallel with those of the first waveguide **101**, and has the H-planes parallel with those of the second waveguide **102**, the fourth waveguide **104** and the fifth waveguide **105** is interposed between the first waveguide **101**, and the second waveguide **102** and the fourth waveguide **104**, whereby transmission of a high-frequency signal from the first waveguide **101** to the second waveguide **102**, the fourth waveguide **104** and the fifth waveguide **105** is enabled.

Third Embodiment

FIG. 6 is a perspective view of a waveguide connecting structure according to a third embodiment.

In the waveguide connecting structure, a first power divider **301** and a second power divider **302** are coupled to the respective openings (the other ends) of the second waveguide and the fourth waveguide shown in FIG. 1.

The power divider **301** includes two sixth waveguides **311A** and **311B**, and a first branching structure (first waveguide branching structure) **312** that branches the other end of the second waveguide **102** into the sixth waveguides **311A** and **311B**. In the first branching structure **312**, reflection suppressing posts **201a**, **201b** and **201c** for suppressing reflection are disposed.

The sixth waveguides **311A** and **311B** and the first branching structure **312** are coupled so that the H-planes are parallel with each other. Accordingly, a high-frequency signal that is inputted from the second waveguide **102** to the first branching structure **312** is respectively branched into the sixth waveguides **311A** and **311B**. Namely, the high-frequency signal is divided into two in power.

The second power divider **302** has a configuration similar to the power divider **301**. Namely, the second power divider **302** includes two seventh waveguides **331A** and **331B**, and a second branching structure (second waveguide branching structure) **332** that branches the other end of the fourth waveguide **104** into the seventh waveguides **331A** and **331B**.

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In the second branching structure **332**, reflection suppressing posts **231a**, **231b** and **231c** for suppressing reflection are disposed.

The seventh waveguides **331A** and **331B** and the second branching structure **332** are coupled so that the H-planes are parallel with each other. Accordingly, a high-frequency signal that is inputted from the fourth waveguide **104** to the second branching structure **332** is respectively branched into the seventh waveguides **331A** and **331B**. Namely, the high-frequency signal is divided into two in power.

As above, according to the present embodiment, a high-frequency signal can be branched into four through the second and the fourth waveguides from the first waveguide.

Fourth Embodiment

FIG. 7 is a perspective view of a waveguide connecting structure according to a fourth embodiment.

The waveguide connecting structure is a structure in which the first power divider **301**, the second power divider **302** and a third power divider **303** are respectively coupled to the respective openings (the other ends) of the second waveguide, the fourth waveguide and the fifth waveguide shown in FIG. 2.

The first and the second power dividers **301** and **302** are similar to the third embodiment, and therefore, the description thereof will be omitted.

The third power divider **303** includes two eighth waveguides **351A** and **351B**, and a third branching structure (third waveguide branching structure) **352** which branches the other end of the fifth waveguide **105** into the eighth waveguides **351A** and **351B**. In the third branching structure **352**, reflection suppressing posts **241a** and **241b** for suppressing reflection are disposed.

The eighth waveguides **351A** and **351B** and the third branching structure **352** are coupled to each other in such a manner that H-planes thereof are parallel with each other. Accordingly, a high-frequency signal that is inputted from the other end of the fifth waveguide **105** into the third branching structure **352** is branched into the eighth waveguides **351A** and **351B** respectively. Namely, the high-frequency signal which is coupled to the fifth waveguide **105** from the first waveguide **101** is divided in two in power.

As above, according to the present embodiment a high-frequency signal can be branched into six from the first waveguide through the second, the fourth and the fifth waveguides.

Fifth Embodiment

FIG. 8 is a perspective view of a waveguide connecting structure according to a fifth embodiment.

The structure is the configuration similar to the fourth embodiment shown in FIG. 7 and is realized by using a dielectric substrate.

A dielectric substrate **501** has both surfaces covered with metallic films **501A** and **501B**. The metallic film is, for example, a copper foil film. In the dielectric substrate **501**, via-holes that penetrate through the metallic films **501A** and **501B** are disposed with spaces from each other. An array of the via-holes disposed with spaces from each other forms the electric field planes of the second waveguide **102**, the first and the second shorted planes of the third waveguide **103**, the electric field planes of the third waveguide **103**, the electric field planes of the fourth waveguide **104**, and the electric field planes of the fifth waveguide **105**. Note that among the via-holes, those assigned with reference signs **201a**, **201b**, **201c**,

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231a, **231b**, **231c**, **241a**, and **241b** are reflection suppressing posts. The via-holes assigned with no reference signs correspond to the via-holes that form the electric field planes and the first and the second shorted planes described above.

Further, the magnetic field planes of the second waveguide **102**, the magnetic field planes of the third waveguide **103**, the magnetic field planes of the fourth waveguide **104**, and the magnetic field planes of the fifth waveguide **105** are formed by parts of the metallic films **501A** and **501B** which are surrounded by the via-holes which forms the respective electric field planes.

The waveguide which is configured by the via-hole array and the metallic films like this is called a post wall waveguide, a dielectric waveguide (or substrate integrated waveguide) or the like.

Note that the coupling window **104A** which couples the first waveguide **101** is formed as an opening that is formed in the metallic film **501B** on the dielectric substrate.

The waveguide connecting structure is configured by using a dielectric substrate, and thereby, reflectance properties can be improved on a wide band.

Although in the present embodiment, an example of realizing the structure similar to FIG. 7 with the dielectric substrate is shown, the structures of FIGS. 1, 4 and 6 can be similarly realized with dielectric substrates.

Sixth Embodiment

FIG. 9 shows a slot array antenna that is connected to the waveguide connecting structure shown in FIG. 7 or FIG. 8. The slot array antenna is connected to the waveguide connecting structure, and thereby an antenna device is formed.

The slot array antenna includes six waveguides **901A**, **901B**, **901C**, **901D**, **901E** and **901F**, and slots **902** that are respectively formed on surfaces of the respective waveguides. These waveguides may be post wall waveguides that are formed on a dielectric substrate. One ends (lower sides) of the waveguides **901A** to **901F** are connected to the first power divider **301**, the third power divider **303** and the second power divider **302** shown in FIG. 7 or FIG. 8.

Specifically, the one ends of the waveguides **901A** and **901B** are connected to the sixth waveguides **311A** and **311B** in the first power divider **301**. The one ends of the waveguides **901C** and **901D** are connected to the eighth waveguides **351A** and **351B** in the third power divider **303**. The one ends of the waveguides **901E** and **901F** are connected to the seventh waveguides **331A** and **331B** in the second power divider **302**.

High-frequency signals that are inputted into the waveguides **901A** to **901F** from the power dividers **301**, **303** and **302** are irradiated into a space as radio waves via the slots **902**.

In the present embodiment, the slot array antenna with the number of elements being six, which is connected to the waveguide connecting structure shown in FIG. 7 or FIG. 8 is shown. An antenna device in which a slot array with the number of elements being four is connected to the waveguide connecting structure shown in FIG. 6 can be similarly configured.

Seventh Embodiment

FIG. 10 shows a configuration example of a reception circuit of a radar device according to the present embodiment. The radar device is an example of a radar device that performs angle measurement by a monopulse system.

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The radar device includes antennas **1001a**, **1001b**, **1001c** and **1001d**, an RF module unit **1002**, an AD converting unit **1003**, a monopulse DBF ("Digital Beam Forming") unit **1004**.

Each of the antennas **1001a** to **1001d** corresponds to the antenna device (the waveguide connecting structure and the slot array antenna) described in the sixth embodiment. A connecting unit between each of the antennas and the RF module unit **1002** corresponds to the first waveguide unit **101** respectively.

The RF module **1002** performs processing that includes down conversion of signals received in the antennas **1001a**, **1001b**, **1001c** and **1001d** which are sub array antennas, and sends the result of the processing to the AD converting unit **1003**.

The AD converting unit **1003** generates a digital signal by subjecting the signal sent from the RF module to analog-digital conversion, and sends the generated digital signal to the monopulse DBF unit **1004**.

The monopulse DBF unit **1004** estimates a position of a target by using the digital signal sent from the AD converting unit **1003**. For the position estimation of the target, a well-known technique is used, and therefore, description of the detailed operation will be omitted.

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

The invention claimed is:

1. A waveguide connecting structure, comprising:

a first waveguide including a pair of electric field planes and a pair of magnetic field planes;

a second waveguide including a pair of electric field planes and a pair of magnetic field planes;

a third waveguide including a pair of electric field planes and a pair of magnetic field planes; and

a fourth waveguide including a pair of electric field planes and a pair of magnetic field planes,

wherein the third waveguide has

a first coupling window formed at one of the magnetic field planes of the third waveguide,

a second coupling window formed at one of the electric field planes of the third waveguide,

a third coupling window formed at the other one of the electric field planes of the third waveguide, and

a first shorted plane and a second shorted plane that close ends of the third waveguide,

the first coupling window couples one end of the first waveguide to the third waveguide in such a manner that the electric field planes of the first waveguide are in parallel with the electric field planes of the third waveguide,

the second coupling window couples one end of the second waveguide to the third waveguide in such a manner that the electric field planes of the second waveguide is in parallel with the magnetic field planes of the first waveguide, and

the third coupling window couples one end of the fourth waveguide to the third waveguide in such a manner that

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the electric field planes of the fourth waveguide is in parallel with the magnetic field planes of the first waveguide.

2. The structure according to claim 1, further comprising:
 a fifth waveguide including a pair of electric field planes
 and a pair of magnetic field planes, 5
 wherein a fourth coupling window is formed at the first shorted plane and
 the fourth coupling window couples one end of the fifth
 waveguide to the third waveguide in such a manner that 10
 the electric field planes of the fifth waveguide is in parallel with the electric field planes of the first waveguide.

3. The structure according to claim 2, comprising:
 a plurality of sixth waveguides; 15
 a plurality of seventh waveguides;
 a plurality of eighth waveguides;
 a first waveguide branching structure branching the other
 end of the second waveguide into the sixth waveguides;
 a second waveguide branching structure branching the 20
 other end of the fourth waveguide into the seventh waveguides; and
 a third waveguide branching structure branching the other
 end of the fifth waveguide into the eighth waveguides.

4. The structure according to claim 3, wherein 25
 the first to third waveguide branching structures include reflection suppressing posts arranged therein.

5. The structure according to claim 1, comprising:
 a plurality of fifth waveguides;
 a plurality of sixth waveguides; 30
 a first waveguide branching structure branching the other
 end of the second waveguide into the fifth waveguides;
 and
 a second waveguide branching structure branching the 35
 other end of the fourth waveguide into the sixth waveguides.

6. An antenna device, comprising:
 the waveguide connecting structure according to claim 5;
 and
 a slot array antenna connected to the waveguide connecting 40
 structure.

7. A radar device, comprising:
 a plurality of antenna devices each being the antenna
 device according to claim 6;
 an RF (Radio Frequency) module unit configured to per- 45
 form processing including down conversion that sub-
 jects signals received at the plurality of antenna devices
 to frequency conversion to obtain conversion signals;
 an analog-digital converting unit configured to subject the
 conversion signals to analog-digital conversion to obtain
 digital signals; and

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a monopulse DBF (Digital Beam Forming) unit configured
 to estimate a position of a target by using the digital
 signals.

8. The structure according to claim 1,
 wherein the electric field planes of the second waveguide,
 the first and the second shorted planes of the third
 waveguide, the electric field planes of the third
 waveguide, and the electric field planes of the fourth
 waveguide are formed by via-holes that is formed in a
 dielectric substrate both surfaces of which are covered
 with metallic films, and
 the magnetic field planes of the second waveguide, the
 magnetic field planes of the third waveguide, and the
 magnetic field planes of the fourth waveguide are
 formed by parts of the metallic films surrounded by the
 via-holes that form respective electric field planes of the
 second waveguide and the fourth waveguide.

9. The structure according to claim 1,
 wherein the second shorted plane continues to one of the
 electric field planes of the second waveguide.

10. The structure according to claim 1,
 wherein the second shorted plane continues to one of the
 electric field planes of the fourth waveguide.

11. The structure according to claim 1,
 wherein the second waveguide, the fourth waveguide and
 the third waveguide are integrally formed physically.

12. The structure according to claim 1,
 wherein the magnetic field planes of the third waveguide
 are at same heights as those of the magnetic field planes
 of the second waveguide or the magnetic field planes of
 the fourth waveguide.

13. The structure according to claim 1,
 wherein the magnetic field planes of the third waveguide
 are at different heights from those of the magnetic field
 planes of the second waveguide or the magnetic field
 planes of the fourth waveguide.

14. The structure according to claim 1,
 wherein the third waveguide forms an H-bend structure
 with the second waveguide.

15. The structure according to claim 1,
 wherein the third waveguide forms an H-bend structure
 with the fourth waveguide.

16. The structure according to claim 1,
 wherein the first coupling window is formed such that a
 size of a side that is parallel with the first shorted plane
 is longer than that of a side that is perpendicular to the
 shorted plane.

17. The structure according to claim 1,
 wherein the first waveguide and the third waveguide are
 integrally formed.

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